

(19)



(11)

EP 4 535 625 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
09.04.2025 Bulletin 2025/15

(51) International Patent Classification (IPC):
H02K 5/22 (2006.01) **H02K 5/18** (2006.01)
H02K 21/24 (2006.01) **H02K 11/40** (2016.01)

(21) Application number: **24199665.1**

(52) Cooperative Patent Classification (CPC):
H02K 11/33; H02K 3/26; H02K 5/18; H02K 5/225;
H02K 9/06; H02K 11/40; H02K 21/24;
H02K 1/2798; H02K 2211/03; H02K 2213/09;
H02K 2213/12

(22) Date of filing: **11.09.2024**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL
NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH MA MD TN

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(30) Priority: **27.09.2023 US 202318373578**

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(54) MODULAR AXIAL FIELD ROTARY ENERGY DEVICE WITH PCB STATOR AND VARIABLE FREQUENCY DRIVE SYSTEM

(57) A system can include an axial field rotary energy device with an axis of rotation and a rotor coaxial with the axis and having a shaft, bearings, rotor disks that are coaxial and permanent magnets on each rotor disk. A printed circuit board (PCB) stator is located between the rotor disks to define an air gap on each side of the PCB stator. An enclosure has two enclosure sections with an

inspection port. Bearing caps and bearings are mounted to the rotor. A variable frequency drive (VFD) assembly is coupled to the axial field rotary energy device. The VFD has a flexible conduit that extends between the VFD housing and the axial field rotary energy device. The flexible conduit can adapt to different sizes of axial field rotary energy devices.

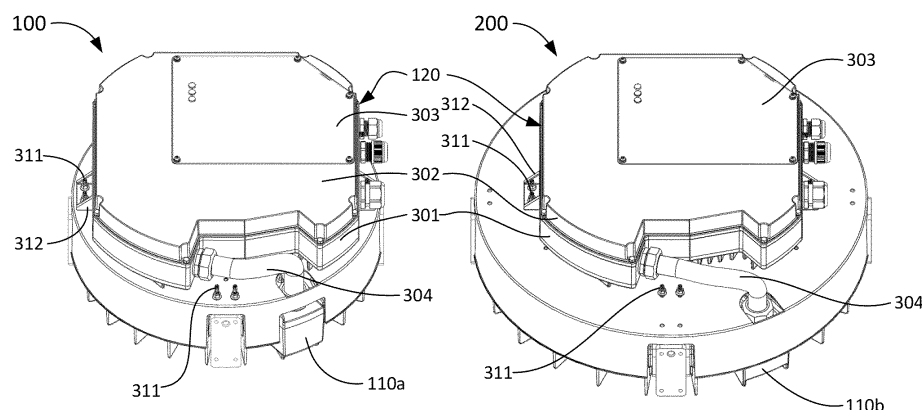


FIG. 6A

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] This disclosure relates in general to electric motors and, in particular, to a system, method and apparatus for an electronic commutated motor (ECM) comprising an axial field rotary energy device with a printed circuit board (PCB) stator and an integrated variable frequency drive (VFD).

Description of the Prior Art

[0002] Axial field rotary energy devices such as those described in US Patents 10,141,803, 10,135,310, 10,340,760, 10,141,804 and 10,186,922 (which are incorporated herein by reference in their entirety) use a variable frequency drive (VFD) to operate when connected to a 60 or 50 Hz alternating current (AC) source. US Patents 11,183, 896 and 11,509,179 (also incorporated herein by reference in their entirety) propose systems where axial field rotary energy devices are coupled to VFDs and can operate connected to 60 or 50 Hz alternating current (AC) sources.

[0003] FIG. 1 depicts examples of such systems with power ratings ranging from 3,73 to 11,19 Kilowatt that equals 5 to 15 horse power (hp). It can be seen in those examples that as the size of the axial field rotary energy device increases as a function of the device's power, the size of the VFD enclosure increases at the same rate. For example, diameter 1 (D1) is larger than D2, D2 is larger than D3, and D3 is larger than D4 in FIG. 1.

[0004] Thus, each machine can require different parts and tooling to build those systems. Another undesirable effect of the increase in size of the VFD enclosure is the added overall weight of the axial field rotary energy device and VFD system.

[0005] In order to simplify and streamline manufacturing processes and reduce volume and weight of the axial field rotary energy device and VFD system, it is desirable to have a VFD package that occupies substantially the same volume independently of its power rating and can be coupled to enclosures of axial field rotary energy devices independently of their rating.

SUMMARY

[0006] The above identified desires and problems are solved by the features of the independent claims. Advantageous embodiments can be derived from the respective dependent claims.

[0007] In an aspect of the present disclosure, a system comprises an axial field rotary energy device and a variable frequency drive (VFD) assembly coupled to the axial field rotary energy device. The system may also be referred to as VFD integrated system.

[0008] In some implementations, the axial field rotary energy device in such a VFD integrated systems can operate as a motor, such as an electronic commuted motor.

5 **[0009]** In some implementations, the axial field rotary energy device in these VFD integrated systems can operate as a generator, where the axial field rotary energy device may operate as an alternator, and the VFD assembly may operate as an AC/AC power converter providing the integration to an external grid or powering an islanded load.

[0010] The axial field rotary energy device of said system comprises an axis of rotation.

10 **[0011]** The axial field rotary energy device further comprises a rotor coaxial with the axis and having a shaft, bearings, rotor disks that are coaxial, permanent magnets on each rotor disk, and the permanent magnets on each rotor disk face toward each other.

15 **[0012]** The axial field rotary energy device of said system further comprises a printed circuit board (PCB) stator located axially between the rotor disks to define an air gap on each side of the PCB stator between the PCB stator and each of the rotor disks. For operation of the axial field rotary energy device, the air gaps can have substantially the same width.

20 **[0013]** The axial field rotary energy device further comprises an enclosure having two enclosure sections. The two enclosure sections of the axial field rotary energy device when coupled together can secure the PCB stator.

25 **[0014]** The two enclosure sections of the axial field rotary energy device may be clam shell enclosure sections.

30 **[0015]** At least one of the enclosure sections has an inspection port oriented radially, relative to the axis, and aligned with the PCB stator and the air gaps between the PCB stator and the rotor disks, such that the inspection port provides a direct line of sight to the air gaps. Advantageously, the at least one inspections port can provide physical access to the interior of the axial field rotary energy device for a direct measurement of the air gaps after the axial field rotary energy device is assembled.

35 **[0016]** The axial field rotary energy device may comprise more than one, e.g. four, inspection ports that are uniformly spaced around the circumference of one of the enclosure sections. The number and positioning of the inspection ports is not limiting, the spacing between them can be non-uniform.

40 **[0017]** Each inspection port can be sealed with a removable threaded plug that provides protection against ingress of water or dust into the axial field rotary energy device.

45 **[0018]** The axial field rotary energy device further comprises bearing caps and bearings mounted to the rotor. So, the rotor may be rotatably mounted to the respective enclosure sections, such as with bearings respectively.

[0019] The bearings may have different sizes per axial field rotary energy device.

[0020] A first bearing of the bearings may be a roller

bearing. A second bearing of the bearings may be a ball bearing.

[0021] Each enclosure section may be configured to receive a bearing cap. Further, each enclosure section may be configured to receive a gasket or O-ring. With such an arrangement, there is provided a seal between each of enclosure sections and the respective bearing caps to prevent the ingress of contaminants into the respective bearings. Advantageous it is now possible to position the rotor disks axially relative to the PCB stator and to establish the air gaps between the PCB stator and the respective rotor disks.

[0022] The axial field rotary energy device further comprises at least one annular shim located between a respective bearing cap and a respective bearing. So, it is possible to provide a bearing pre-load and to position the rotor axially in relation to the enclosure sections.

[0023] An axial position of the rotor may be adjusted, and widths of the air gaps may be changed by adding or removing annular shims. So, the air gaps can be easily adjusted by removing the annular shim from the space between one bearing cap and its respective bearing, or by adding an annular shim to the space between the opposing bearing cap and its respective bearing. Additionally, the bearing caps, the at least one annular shim and the bearings can now form an assembly where the rotor does not move axially during operation independently of the orientation of the axis of rotation (horizontal, vertical, or inclined). Furthermore, it allows the axial field rotary energy device to be mounted vertically with the drive end pointing up or down.

[0024] Each annular shim may have a different thickness to provide a wide range of adjustments for the air gaps.

[0025] The system further comprises the VFD assembly coupled to the axial field rotary energy device. Hereinafter, the VFD assembly refers to the electronics that comprises a functional VFD and its enclosure.

[0026] The VFD assembly comprises a flexible conduit that extends between a VFD housing (also referred to as housing) and the axial field rotary energy device, wherein the flexible conduit is configured to adapt to different sizes of axial field rotary energy devices.

[0027] Preferably, the VFD assembly further comprises a rectifier module, a DC bus module, an inverter module, and a control module, hereinafter commonly referred to as VFD electronics.

[0028] Preferably, the VFD housing is configured to receive VFD electronics, such as a PCB assembly that comprises the VFD electronics, preferably all on one single board.

[0029] The VFD housing may comprise a main cover and an access cover.

[0030] The VFD housing may comprises a plurality of fins located along two opposite sides of the VFD housing to enhance the heat removal. The airflow generated by impeller can be further directed towards these fins, e.g. by air guides.

[0031] Preferably, the axial field rotary energy device may have captive fasteners configured to engage mechanically with respective VFD brackets that are coupled to the VFD housing.

[0032] Advantageously, while an enclosure of the axial field rotary energy device can increase or decrease in size as a function of its power or its torque, an enclosure of the VFD as described herein can have the same or substantially the same physical dimensions regardless of the power rating of the respective axial field rotary energy device. Hereinafter the term "size" may be used synonymously with the term "dimensions", "outer diameter" .

[0033] There may be one of the two enclosure sections on a drive end of the axial field rotary energy device and the other one of the two enclosure sections may be on a non-drive end of the axial field rotary energy device.

[0034] At least one of the bearing caps may comprise a grounding brush. Preferably, the at least one of the bearing caps has a slot configured to receive the grounding brush, e.g. that can be mounted to gently touch the shaft of the rotor. Advantageously, this grounding brush may prevent parasitic currents from circulating through the bearings which can damage and shorten their life. In some implementations, only one grounding brush is mounted on a bearing cap on the drive end. In other implementations, grounding brushes are mounted on each bearing cap.

[0035] The system may further comprise an impeller coupled to the shaft of the rotor. For that, the shaft may have a keyway that aligns axially and engages a tab on a bore of the impeller. So, the impeller can provide an air flow to cool the axial field rotary energy device and the VFD assembly of the VFD integrated system.

[0036] The impeller may have retention tabs that engage with a groove in the shaft to retain the impeller on the shaft, e.g. when the impeller is fully seated on the shaft.

[0037] The impeller may be disposed only on a non-drive end of the axial field rotary energy device. In some implementations, one impeller is disposed on a non-drive end of the axial field rotary energy device and another impeller is disposed on a drive end of the axial field rotary energy device.

[0038] The system wherein at least one of the bearing caps comprises a grounding brush and the bearings have different sizes.

[0039] The system further comprising an impeller coupled to the shaft of the rotor, wherein the impeller has retention tabs that engage with a groove in the shaft to retain the impeller on the shaft, and at least one of the bearing caps comprises a grounding brush.

[0040] The system wherein the bearings have different sizes.

[0041] The system further comprising an impeller coupled to the shaft of the rotor, wherein the impeller has retention tabs that engage with a groove in the shaft to retain the impeller on the shaft, and the bearings have different sizes.

[0042] The system further comprising a metal shim

located between the PCB stator and at least one of the enclosure sections of the axial field rotary energy device, wherein the metal shims axially couple the PCB stator to the enclosure sections to transfer heat from the PCB stator to the enclosure sections.

[0043] The system further comprising metal shims located between the PCB stator and at least one of the enclosure sections of the axial field rotary energy device, wherein the metal shims axially couple the PCB stator to the enclosure sections to transfer heat from the PCB stator to the enclosure sections.

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[0047] The system further comprising metal shims located between the PCB stator and at least one of the enclosure sections of the axial field rotary energy device, wherein the metal shims axially couple the PCB stator to the enclosure sections to transfer heat from the PCB stator to the enclosure sections.

[0048] The system wherein the metal shims comprise copper foam.

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[0050] The system wherein the metal shims comprise copper foam.

[0051] The system further comprising metal shims located between the PCB stator and at least one of the enclosure sections of the axial field rotary energy device, wherein the metal shims axially couple the PCB stator to the enclosure sections to transfer heat from the PCB stator to the enclosure sections.

[0052] The system wherein the metal shims comprise copper foam.

[0053] The system wherein the axial field rotary energy device and the VFD housing achieve a degree of protection IP54 according to IEC60034-5 or higher.

[0054] Embodiments of systems comprising an axial field rotary energy device and respective variable fre-

quency drive (VFD) are disclosed. Hereinafter, these embodiments can be referred to as a VFD integrated system, a motor-VFD assembly, etc. For example, the VFD integrated system can include an axial field rotary energy device having a printed circuit board (PCB) stator coaxial with rotor disks having respective permanent magnets. The PCB stator can be located axially between the rotor disks that are coupled to a common shaft that can rotate about an axis of rotation. The rotor disks and PCB stator can be positioned inside an enclosure, e.g. a clam shell enclosure, having features that allow for inspecting and adjusting the mechanical air gaps between the PCB stator and respective rotor disks without disassembling the axial field rotary energy device. The VFD can be located in a separate enclosure with mounting features that enable attaching the VFD to enclosures of different sizes of axial field rotary energy devices. The VFD enclosure can have features that provide water and dust ingress protection meeting IP54 or IP55 degree of protection as per IEC60034-5, for example.

[0055] The VFD enclosure can provide selective access to parts of the VFD electronic circuit facilitating connection of power or control cables to the VFD while preventing users from touching electrically charged components, such as capacitors, for example. The VFD enclosure also can have features that provide visual information about the status of the VFD without having to open the enclosure or remove covers. Furthermore, the VFD enclosure can have features to capture and dissipate the heat generated by components such as MOSFETs, rectifier bridges and inductors, for example.

BRIEF DESCRIPTION OF THE DRAWINGS

[0056] So that the manner in which the features and advantages of the embodiments are attained and can be understood in more detail, a more particular description can be had by reference to the embodiments that are illustrated in the appended drawings. However, the drawings illustrate only some embodiments and are not to be considered limiting in scope since there can be other equally effective embodiments.

[0057] It shall be noted that some of the details and/or features shown in the drawings herein may not be drawn to scale for clarity purposes and some elements.

FIG. 1 is an isometric view of conventional axial field rotary energy devices and VFD systems.

FIG. 2 is a general schematic view of an embodiment of a VFD integrated system.

FIG. 3 is an isometric view of embodiments of axial field rotary energy devices and VFD systems having a modular VFD enclosure.

FIG. 4A is an isometric view from different angles of an embodiment of an axial field energy device without the VFD enclosure.

FIG. 4B is a sectional side view of the device shown in FIG. 4A.

FIG. 4C is an isometric view of an enlarged portion of the device shown in FIG. 4A.

FIG. 4D is a side view of an enlarged portion of the device shown in FIG. 4A.

FIG. 5A is an exploded, isometric view of an embodiment of an axial field rotary energy device and impeller.

FIG. 5B is an enlarged isometric view of an embodiment of an impeller for an axial field rotary energy device.

FIG. 6A is an isometric view of the VFD integrated systems shown in FIG. 3 from a different angle.

FIG. 6B is a top view of one of the VFD integrated systems shown in FIG. 6A.

FIG. 7A is sectional schematic side view of an embodiment of a VFD integrated system showing its air flow.

FIG. 7B is a bottom view of an embodiment of a VFD enclosure with an impeller.

FIG. 7C is a partial bottom view of an alternate embodiment of the VFD enclosure.

FIG. 7D is a partial sectional side view showing details of the fins in a VFD enclosure.

FIG. 8A is an exploded isometric view of an embodiment of a VFD showing its components.

FIG. 8B is an enlarged isometric view of an embodiment of an I/O and communication module.

FIG. 8C is an isometric view, shown partially sectioned, of an embodiment of the VFD showing its access points.

FIG. 9 is an enlarged sectional side view of an embodiment of the VFD showing its housing and cover details.

FIG. 10 is a sectional side view of an embodiment of the VFD cover.

FIG. 11A is an isometric view of an embodiment of the VFD housing showing internal details.

FIG. 11B is an enlarged isometric view of a portion of the VFD housing showing ferromagnetic core holding details.

FIG. 11C is a sectional side view of a portion of an embodiment of ferromagnetic core mounting details.

FIG. 11D is an enlarged isometric view of a portion of an embodiment of the VFD housing showing switching device mounting details.

FIG. 12 is an enlarged sectional side view of a portion of an embodiment of VFD covers with light pipes.

DETAILED DESCRIPTION

[0058] This disclosure includes embodiments of systems comprising a first enclosure containing an axial field rotary energy device having one or more rotors with magnets, such as permanent magnets, and one or more printed circuit board (PCB) stators, and a second enclosure containing a variable frequency drive (VFD), input and output (I/O) interfaces, inductors, and other components. However, it should be understood that the axial

field rotary energy device in these VFD integrated systems can operate as a motor or as a generator. While the axial field rotary energy device enclosure can increase or decrease in size as a function of its power or torque, the VFD enclosure in the embodiments described herein can have the same size or substantially the same size regardless of the power rating of the respective axial field rotary energy device.

[0059] FIG. 2 shows a general schematic view of an embodiment of a VFD integrated system 100 comprising an axial field rotary energy device 110 and a VFD assembly 120. Hereinafter, a "VFD 120" refers to the electronics that comprise a functional VFD and its enclosure. In this embodiment, an axial field rotary energy device 110 can be coupled to an inverter module 121 of a VFD 120 through line inductors 130. In other versions, the line inductors 130 can be absent, such that the axial field rotary energy device 110 can be connected directly to the inverter module 121 of the VFD 120. While the example shown in FIG. 2 depicts a 3-phase motor connected to a 3-phase inverter, other phase arrangements are possible, such as 6, 9 or 12-phase devices, just to mention few options without limiting the scope thereto.

[0060] In FIG. 2, the VFD 120 can comprise a rectifier module 122, a DC bus module 123, an inverter module 121, and a control module 124. The rectifier module 122 can be, as an example, a full wave rectifier having passive devices, such as diodes, or active switching devices (e.g., IGBTs, MOSFETs, etc.) to convert the incoming alternating current (AC) from the rectifier input 141 to direct current (DC). In some embodiments, the rectifier input can have ferromagnetic cores 146 in each phase to filter common mode currents. The DC bus 123 can include a bank of capacitors sized to provide stable voltage to the inverter module 121. The inverter module 121 can have, as an example, a 6-pulse 3-phase bridge, which can use active switching devices, such as IGBTs or MOSFETs, controlled by a pulse width modulation (PWM) scheme to convert DC to AC at the frequency required by the axial field rotary energy device 110. However, other inverter topologies can be used, such as 3-level neutral point clamped (NPC) inverter. Although the input to the VFD 120 is typically AC at 60 or 50 Hz, the output frequency of the VFD 120 can range from, for example, a frequency near zero Hz, to a frequency in the hundreds or even thousands of Hz. In some embodiments where the PWM frequencies are high (e.g., above 50 kHz), the inverter module 121 can comprise wide band gap (WBG) devices such as silicon carbide or gallium nitride MOSFETs.

[0061] The VFD integrated system 100 depicted in FIG. 2 can include a control module 124 that provides and receives signals to and from the various modules of the VFD 120. The control module can be coupled to an I/O and communication module 125 (hereinafter referred to as I/O module) configured to receive control signals from an external source through input ports 142, such as a digital signal, to turn the VFD on or off, or an analog

voltage signal that can provide a speed reference to the system. These signals can control the output frequency of the VFD 120, and therefore the speed of the axial field rotary energy device 110. They also can control the current and voltage supplied by the VFD 120 to the axial field rotary energy device 110 to achieve desired torque characteristics, such as operating at a constant torque condition over a certain speed range. FIG. 2 depicts input and output connections 143 and 144 between the control module 124 and the inverter module 121 and rectifier 122, respectively. In some embodiments, some of the input or output connections can be absent. In some embodiments, the control module 124 also can be connected to sensors in the axial field rotary energy device 110 via a separate set of input lines 145. The sensors can include, for example, resistance temperature detectors (RTD), thermocouples, vibration sensors, encoders, and/or other sensors.

[0062] In some embodiments of the VFD integrated system 100, the control module 124 in conjunction with the I/O module 125 can be configured to receive and transmit information to a supervisory control and data acquisition system (SCADA) or other control system. The I/O module 125 can have a communication interface that can be configured to operate various communication protocols including, but are not limited to, Modbus RTU, Modbus TCP/IP, Ethernet, EtherCAT, EtherNet/IP, PROFINET, POWERLINK, SERCOS III, CC-Link IE, BacNET, RS485, LTE-M, and Bluetooth. The I/O module also can accept analog inputs, such as a 0 - 10 V or a 4 - 20 mA.

[0063] Although FIG. 2 depicts a VFD integrated system 100 with the axial field rotary energy device 110 operating as a motor, other embodiments of the VFD integrated systems can be operated as generator systems where the axial field rotary energy device 110 can operate as an alternator, and the VFD 120 can operate as an AC/AC power converter providing the integration to an external grid or powering an islanded load. In these cases, the inverter module 121 can operate as an active rectifier of the AC/AC power converter and the rectifier 122 can have active switching devices such as IGBTs or MOSFETs and operate as an inverter. The control module 124 can provide the signals to control the active rectifier by means of the communication ports 143 and signals to control the inverter through ports 144, for example.

[0064] Embodiments of the VFD 120 can have different power ratings but its housing (enclosure) can have the same size or substantially the same size. FIG. 3 shows examples of VFD integrated systems 100 and 200, where the respective axial field rotary energy devices 110a, 110b can have different power ratings and outer diameters. For example, the VFD integrated system 100 can have a rating of 5.59 Kilowatt (that equals 7.5 horse power (hp)) and a diameter D1 of approximately 380 mm, and the VFD integrated system 200 can have a rating of 11.19 Kilowatt (that equals 15 horse power (hp)) and a

diameter D2 of approximately 520 mm. However, their respective VFDs 120 can occupy the same volume and have the same enclosure.

[0065] FIGS. 4A to 4D show an embodiment of an axial field rotary energy device 110 that can be part of a VFD integrated system. FIG. 4A shows a view from both the drive end side and the non-drive end side of the axial field rotary energy device 110. The axial field rotary energy device 110 can comprise a rotor 202 that can rotate about an axis of rotation 201. The rotor 202 can comprise rotor disks 211 coupled to a shaft 210 that can rotate about the axis of rotation 201 (FIG. 4B). Rotor disks 211 can be coaxial and permanent magnets can be on each rotor disk 211. The permanent magnets on each rotor disk 211 may face toward each other.

[0066] The axial field rotary energy device 110 can further comprise an enclosure formed by two clam shell enclosure sections 203a and 203b. The enclosure section 203a is on the drive end of the axial field rotary energy device 110, and the enclosure section 203b is on the non-drive end. When the two enclosure sections 203a and 203b are coupled together, they can secure the PCB stator 220 (FIG. 4B) which is coaxial with the enclosure sections 203a, 203b. A shim 222 can be positioned on at least one face of the PCB stator 220 and the corresponding enclosure section (203b, for example) to secure the PCB stator 220 axially relative to the enclosure sections 203a and 203b. The shim 222 can be substantially ring-shaped and be made of copper, aluminum, or copper foam, for example, or any other metal alloy or material that is a good thermal conductor so it also can help transfer heat from the PCB stator 220 to the enclosure sections 203a and 203b. The shim 222 can be available in different thicknesses (0.25, 0.50 and 0.75 mm, for example) to accommodate for assembly tolerances. In some embodiments, the shim 222 can be segmented, so a plurality of segments can form a ring.

[0067] The two enclosure sections 203a and 203b are coaxially aligned with each other and are coaxial with the axis of rotation 201 and the rotor 202. The rotor 202 can be rotatably mounted to the respective enclosure sections 203a and 203b, such as with bearings 212a and 212b respectively. While FIG. 4B shows an embodiment of the axial field rotary energy device 110 with same size bearings 212a, 212b, other embodiments can have bearings with different sizes and/or configurations. For example, bearing 212a can be a roller bearing and bearing 212b can be a ball bearing.

[0068] The enclosure sections 203a and 203b can be configured to receive bearing caps 204a and 204b respectively. Each enclosure section 203a, 203b can have a channel 214 configured to receive a gasket, or O-ring, for example, that provides a seal between each of enclosure sections 203a, 203b and the respective bearing caps 204a, 204b to prevent the ingress of contaminants into the respective bearings 212a, 212b. In some embodiments, one or more annular shims 213 (FIG. 4B) can be positioned between the bearing caps 204a and

204b and the respective bearings 212a and 212b to provide bearing pre-load and to position the rotor 202 axially in relation to the enclosure sections 203a and 203b. This feature is advantageous to position the rotor disks 211 axially relative to the PCB stator 220 and establish the air gaps 221a and 221b between the PCB stator 220 and the respective rotor disks 211. For operation of the axial field rotary energy device 110, the air gaps 221a and 221b can have substantially the same width. The air gaps 221a, 221b can be adjusted by removing the annular shim 213 from the space between one bearing cap 204a or 204b and its respective bearing 212a or 212b, and adding an annular shim 213 to the space between the opposing bearing cap 204a, or 204b and its respective bearing 212a, or 212b. For example, by removing the annular shim 213 from the space between the bearing cap 204a and the bearing 212a and adding an annular shim 213 to the space between the bearing cap 204b and the bearing 212b, the rotor 202 can be axially shifted towards the drive end of the axial field rotary energy device 110 to narrow the air gap 221a and widen the air gap 221b. To enable this feature, there can be multiple annular shims 213 in each space between the bearing caps 204a, or 204b and the respective bearings 212a, or 212b. In addition, the annular shims 213 can have different thicknesses to provide a wide range of adjustments of each of the air gaps 221a and 221b. Another advantage of this embodiment is that the bearing caps 204a and 204b, annular shims 213 and bearings 212a and 212b can form an assembly where the rotor 202 does not move axially during operation independently of the orientation of the axis of rotation 201 (horizontal, vertical, or inclined). Furthermore, it allows the axial field rotary energy device 110 to be mounted vertically with the drive end pointing up or down.

[0069] Further in FIG. 4B, one of the enclosure sections 203a, for example, can have a channel 209 configured to receive a gasket, or O-ring, for example, that provides a seal between the two enclosure sections 203a, and 203b to prevent the ingress of water or dust into the axial field rotary energy device 110. This, along with seals in channels 214, can enable the axial field rotary energy device 110 to achieve a degree of protection IP54, IP55 or higher, as per IEC60034-5, for example.

[0070] The bearing caps 204a and 204b (FIG. 4A) can have a slot configured to receive a grounding brush 205 (FIG. 4C) that can be mounted to gently touch the shaft 210 (FIG. 4B) of the rotor 202. This feature is beneficial as it can prevent parasitic currents from circulating through the bearings 212a, and 212b which can damage and shorten their life. FIGS. 4A to 4C show an embodiment of the axial field rotary energy device 110 that has a grounding brush 205 mounted on the bearing cap 204b on the non-drive end. Some embodiments of the axial field rotary energy device 110 can have the grounding brush 205 mounted on the bearing cap 204a on the drive end, while other embodiments of the axial field rotary energy

device 110 can have grounding brushes 205 mounted on both bearing caps 204a and 204b.

[0071] The enclosure section 203a on the drive end can have a mounting flange 231 (FIG. 4A) to facilitate assembling the axial field rotary energy device 110 to a driven equipment or prime mover, depending on whether the axial field rotary energy device 110 is a motor or a generator. The axial field rotary energy device 110 also can be configured with flanges 232 (FIG. 4A) at certain circumferential locations (at every 90 degrees, for example). Each flange can have mounting holes 233 that are parallel to the axis of rotation 201. The flanges 232 can receive removable mounting brackets 234 that can be fastened to the flanges 232 with bolts coupled to the mounting holes 233. These features enable the axial field rotary energy device 110 to be mounted to a frame, for example.

[0072] One of the enclosure sections 203a, for example, of the axial field rotary energy device 110, can have one or more radially-oriented inspection ports 208 (FIGS. 4A and 4D) on the sides thereof. The inspection ports 208 can be aligned with the stator 220 and the air gaps 221a and 221b to provide a direct line of sight to the air gaps 221a and 221b (FIG. 4D). This feature is advantageous because it can provide a view of the interior of the axial field rotary energy device 110 during assembly. The inspection ports 208 also can provide physical access to the interior for a direct measurement of the air gaps after the axial field rotary energy device 110 is assembled. While not being used, the inspection ports 208 can be sealed with a removable threaded plug that provides protection against ingress of water or dust into the axial field rotary energy device 110. As one example, the embodiment shown in FIG. 4A can have four inspection ports 208 that are uniformly spaced around the circumference of the enclosure section 203a. Other axial field rotary energy devices can have a different number of inspection ports and the spacing between the ports can be non-uniform.

[0073] The axial field rotary energy device 110 can have an external impeller 230 (FIGS. 5A and 5B) that can be coaxial with the axis 201 and mounted to the shaft 210 on the non-drive end, for example. The impeller 230 can provide an air flow 310 (FIG. 7A) to cool the axial field rotary energy device 110 and the VFD 120 of the VFD integrated system 100. The impeller 230 and the shaft 210 can have features to facilitate their assembly. For example, the shaft 210 can have a keyway 215 that aligns axially and engages a tab 235 on the bore of the impeller 230. The shaft 210 also can have an annular groove 206 that engages one or more retention tabs 231 on the impeller 230 when the impeller 230 is fully seated on the shaft 210. The impeller 230 can be injection molded and may comprise a structural plastic like ABS, or Nylon 12, or can be made of cast aluminum, for example. While FIGS. 5A and 5B show an embodiment with an impeller 230 on the non-drive end of the axial field rotary energy device 110, some embodiments can have impellers on

both ends. The impeller 230 shown in FIGS. 5A and 5B is configured to operate in clockwise or counterclockwise rotation so it has straight radial blades 236 (FIG. 5B). Other embodiments of the impeller 230 can be configured to rotate in only one direction and can have backward curved blades or forward curved blades, for example.

[0074] FIG. 6A shows the VFD integrated systems 100, and 200 from FIG. 3 at a different angle. The VFD integrated systems 100 and 200 can have axial field rotary energy devices 110a and 110b, respectively, that are substantially different in size, e.g. their outer diameter. The axial field rotary energy device 110b can have a higher power rating and be larger than device 110a, for example. The VFD integrated systems 100 and 200 can have VFDs 120 that have the same size or substantially the same size, so they can have the same VFD enclosure. For that, each VFD 120 can have a (same sized) VFD housing 301 that can be configured to receive the VFD electronics depicted in FIG. 2. The VFD 120 also can have a main cover 302 coupled to the VFD housing 301, and an access cover 303 coupled to the main cover 302. The access cover 303 can have features that facilitate its removal/installation, and to provide selective access to the VFD electronics. As shown in FIGS. 6A and 6B, the axial field rotary energy devices 110a and 110b can have captive fasteners 311 (threaded studs, for example) configured to engage mechanically with VFD brackets 312, which are coupled to the respective VFD housings 301. The spacing between captive fasteners 311 and their location on the respective axial field rotary energy device 110a or 110b, for example, is such that, independently of the size of the axial field rotary energy device, the fasteners 311 can align and engage the brackets 312 on the VFD housing 301. The fasteners 311 also can guide and align axially the VFD 120 to the respective axial field rotary energy device during assembly.

[0075] In addition, the VFD housing 301 can be coupled to the respective axial field rotary energy device through a flexible conduit 304 configured to adapt to different sizes of axial field rotary energy devices 110a, or 110b, as shown in FIG. 6A. As an example, embodiments of the VFD 120 may have different power ratings but can have the same size or substantially the same size. As already shown in FIG. 3, there are examples of VFD integrated systems 100 and 200, where the respective axial field rotary energy devices 110a, 110b can have different power ratings and outer diameters (in the meaning of different sizes). For example, the VFD integrated system 100 can have a rating of 5,59 Kilowatt (that equals 7.5 horse power (hp)) and a diameter D1 of approximately 380 mm, and the VFD integrated system 200 can have a rating of 11,19 Kilowatt (that equals 15 horse power (hp)) and a diameter D2 of approximately 520 mm. However, their respective VFDs 120 can occupy the same volume and have the same enclosure.

[0076] Different versions of VFD integrated systems 100, and 200 have been shown in FIGS. 3 and 6A to

illustrate the interchangeability of the VFD 120 and its enclosure relative to different versions of the respective axial field rotary energy devices 110a, and 110b. Hereinafter, the VFD integrated system will be referred to with the reference numeral 100, but it should be understood that VFD integrated system 100 can be different sizes and versions.

[0077] FIG. 7A shows a schematic sectional view of the VFD integrated system 100 where some parts are not shown to illustrate how the airflow 310 can circulate between the axial field rotary energy device 110 and the VFD 120. The airflow 310 can be generated by the impeller 230 coupled to the shaft 210, while the shaft 210 rotates about the axis of rotation 201. The airflow 310 can be guided by a shroud 307 around fins 240 that can be part of the enclosure section 203b of the axial field energy rotary device 110. The airflow 310 is then directed toward a substantially circular opening 308 approximately at the center of the shroud 307 from where it can be pushed outward by the impeller 230 over fins 305 of the VFD housing 301.

[0078] As shown in FIG. 7B, the VFD housing 301 can have a plurality of fins 305a and 305b located along two opposite sides thereof in a converging pattern that can accelerate the air velocity as it moves along the fins 305a, 305b to enhance the heat removal. The airflow generated by the impeller 230 can be further directed towards the fins 305a and 305b by air guides 306, which can have a converging arrangement similar to the fins 305a, 305b. In addition to increasing the air velocity, the converging fin pattern also can increase the fin density in the areas of the VFD housing 301 that have a higher heat load to promote a more effective heat transfer to the cooling airflow. For example, fins 305a can be tightly packed in the area where the switching devices 350 (represented by dotted rectangles) are mounted inside the VFD housing 301. Similarly, fins 305b can be tightly packed in the area where inductors 130 (represented by dotted circles) and ferromagnetic cores 145 (represented by dotted rectangles) are mounted inside the VFD housing 301.

[0079] While FIG. 7B shows an embodiment of the VFD housing 301 with fins 305a, 305b that are substantially straight. As shown in FIG. 7C, other embodiments of the VFD housing 301 can have fins 305 with a curved profile. The fins 305 can have sloped leading edges 309 (FIG. 7D) that can reduce air drag losses to promote a more efficient air flow pattern. Furthermore, the sloped leading edges 309 collectively can form an elliptical pattern (represented by the curved dashed lines in FIGS. 7B and 7C) around the impeller 230 to enhance the capture of the air flow generated by the impeller 230 and allow for bi-directional operation of the impeller 230.

[0080] In the embodiment shown in FIG. 8A, the VFD housing 301 is configured to receive a printed circuit board assembly (PCBA) 320 that can comprise the rectifier module 122, inverter module 121, DC bus 123, and control module 124 shown in FIG. 2, all on one single board. The VFD housing 301 also can have other com-

ponents such as inductors 130 (FIG. 8A) and ferromagnetic cores 146, which can be held in place by a molded clamp 326. An I/O module 125 also can be mounted on a metal shield plate 322 that can deflect some of the electromagnetic emissions produced by the inverter module 121, so they do not interfere with the operation of the I/O module 125. The I/O module 125 can be attached to the shield plate 322 with snap-in supports 318 (FIG. 8B) that allow for quick installation and removal. The shield plate 322 can be located above the PCBA 320 and secured with standoffs 317 (FIG. 8B). The I/O module 125 also can be behind a safety barrier 324 (FIGS. 8A and 8C) that allows only selective access to power terminals 321 and communication terminals 325a and 325b when the access cover 303 is removed.

[0081] Some embodiments of the VFD 120 can be configured to meet IP54 or IP55 degree of protection as per IEC60034-5, for example. In those cases, the main cover 302 can have a channel that can receive a seal 327 (FIG. 9). The seal 327 can engage a raised edge 328 in the VFD housing 301. When the main cover 302 is fastened to the VFD housing 301, the raised edge 328 can compress the seal 327 to prevent water or dust from entering the VFD 120. The seal 327 can be an O-ring or an extruded gasket, for example. The VFD housing 301 can comprise a thermally conductive material such as cast aluminum, for example. In some embodiments, where shielding against electromagnetic interference (EMI) is desired, the main cover 302 can be made of a conductive material such as cast aluminum or molded plastic with a conductive metallic coating. In those cases, the seal 327 can be conductive.

[0082] Similar to the interface between the VFD housing 301 and main cover 302, the access cover 303 (FIG. 9) can have a channel configured to receive a seal 331 that can engage a raised edge 332 on the main cover 302. When the access cover 303 is fastened to the main cover 302, the raised edge 332 can compress the seal 331 to prevent water or dust from entering the VFD 120. The seal 331 can be an O-ring or an extruded gasket, for example. In embodiments where shielding against electromagnetic interference (EMI) is desired, the main cover 302 and access cover 303 can be made of a conductive material such as cast aluminum or molded plastic with a metallic conductive coating. In those cases, the seal 331 can be conductive. The access cover 303 can be configured to be easily removed from and reinstalled on the main cover 302 with captive fasteners 333 (FIG. 10) that can stay permanently attached to the cover 303.

[0083] The VFD housing 301 can have features to facilitate the assembly of the VFD components and to remove heat from those components during operation of the VFD integrated system 100. As shown in FIG. 11A, the VFD housing 301 can have concave cradles 340 configured to receive ferromagnetic cores 146 (FIG. 11B). The ferromagnetic cores 146 can be held in place by a core clamp 326 that is fastened to bosses 341 with screws 348 (FIG. 11B), for example. As shown in FIG.

11C, the concave cradles 340 can have contours 339 that closely match the outer surface of the ferromagnetic cores 146 to enhance surface contact therebetween, reduce thermal resistance, and facilitate heat removal. FIG. 11B shows an embodiment where not all concave cradles 340 are populated with ferromagnetic cores 146. Other embodiments of the VFD 120 can have both concave cradles 340 populated with ferromagnetic cores 146. Some embodiments can have the core clamp 326 made of a non-conductive material such as ABS or nylon 12, for example. Other embodiments can have the core clamp 326 made of a conductive material such as die-cast aluminum or stamped steel, for example.

[0084] Back to FIG. 11A, the VFD housing 301 can have pads 342 configured to receive inductors 130 (FIG. 8A). Another pad 343 can be configured to receive and function as a heatsink for a rectifier module that can be part of the PCBA 320 (FIG. 8A). In addition, the VFD housing 301 can have a plurality of standoffs 345 integral to the VFD housing, and configured to support the PCBA 320. The VFD housing 301 also can have pads with wire loops 347 configured to receive tie wraps, for example, to secure electrical cables that connect the components of the VFD. Furthermore, the VFD housing 301 can have a pad 346 configured to receive and function as a heatsink for the active switching devices (IGBTs or MOSFETs for example) of the PCBA 320.

[0085] FIG. 11D shows details of how the switching devices 350 can be mounted on the pad 346 of the VFD housing 301. The pad 346 can have alignment pins 349 configured to receive and align thermal interface pads 351 and respective switching devices 350. The switching device 350 can be held in place by a spring clip 352 attached to the VFD housing 301 by the fastener 353. The spring clips 352 are configured to provide a uniform clamping force to the respective switching device 350 independently of the torque applied to fasteners 353. This arrangement is advantageous because it prevents the application of excessive force that could damage the switching device 350. In addition, as the thermal resistance between the switching device 350, its respective thermal interface pad 351, and the pad 346 can be affected by the force applied by the spring clip 352, the uniform clamping force can result in uniform thermal resistance and, therefore, uniform temperature of the switching devices 350 during operation. While the pad 346 in FIG. 11D is configured to receive six switching devices, other embodiments of the VFD housing 301 can have pads configured to receive a different number of switching devices.

[0086] In some embodiments of the VFD 120, like the one shown in FIG. 12, the I/O module 125 can have one or more LEDs 126 that can indicate the status of the VFD. For example, a green LED can indicate normal operation, or red LED can indicate power on. To make the status of the LEDs 126 visible to users, the access cover 303 (FIGS. 8A and 12) can have light pipes 313 mounted to it. When the access cover 303 is fastened to the VFD

main cover 302 (FIG. 12), the light pipes 313 can extend through openings 329 in the safety barriers 324, and be aligned with the LEDs 126 making their status visible externally without the need to remove the access cover 303 or the safety barrier 324. FIG. 8A shows an embodiment of the VFD 120 with three light pipes 313 attached to the access cover 303. Other versions can have a different number of light pipes.

[0087] The terminology used herein is for the purpose of describing particular example embodiments only and is not intended to be limiting. As used herein, the singular forms "a," "an," and "the" may be intended to include the plural forms as well, unless the context clearly indicates otherwise. The terms "comprises," "comprising," "including," and "having," are inclusive and therefore specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. The method steps, processes, and operations described herein are not to be construed as necessarily requiring their performance in the particular order discussed or illustrated, unless specifically identified as an order of performance. It is also to be understood that additional or alternative steps may be employed.

[0088] When an element or layer is referred to as being "on," "engaged to," "connected to," or "coupled to" another element or layer, it may be directly on, engaged, connected or coupled to the other element or layer, or intervening elements or layers may be present. In contrast, when an element is referred to as being "directly on," "directly engaged to," "directly connected to," or "directly coupled to" another element or layer, there may be no intervening elements or layers present. Other words used to describe the relationship between elements should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," etc.). As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items.

[0089] Although the terms first, second, third, etc. may be used herein to describe various elements, components, regions, layers and/or sections, these elements, components, regions, layers and/or sections should not be limited by these terms. These terms may be only used to distinguish one element, component, region, layer or section from another region, layer or section. Terms such as "first," "second," and other numerical terms when used herein do not imply a sequence or order unless clearly indicated by the context. Thus, a first element, component, region, layer or section discussed below could be termed a second element, component, region, layer or section without departing from the teachings of the example embodiments.

[0090] Spatially relative terms, such as "inner," "outer," "beneath," "below," "lower," "above," "upper," "top," "bottom," and the like, may be used herein for ease of

description to describe one element's or feature's relationship to another element(s) or feature(s) as illustrated in the figures. Spatially relative terms may be intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "below" or "beneath" other elements or features would then be oriented "above" the other elements or features. Thus, the example term "below" can encompass both an orientation of above and below. The device may be otherwise oriented (rotated degrees or at other orientations) and the spatially relative descriptions used herein interpreted accordingly.

[0091] This written description uses examples to disclose the embodiments, including the best mode, and also to enable those of ordinary skill in the art to make and use the invention. The patentable scope is defined by the claims, and can include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

[0092] In the foregoing specification, the concepts have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the invention as set forth in the claims below. Accordingly, the specification and figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of invention.

[0093] It can be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The term "communicate," as well as derivatives thereof, encompasses both direct and indirect communication. The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrase "associated with," as well as derivatives thereof, can mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like. The phrase "at least one of," when used with a list of items, means that different combinations of one or more of the listed items can be used, and only one item in the list can be needed. For example, "at least one of: A, B, and C" includes any of the following combinations: A, B, C, A and B, A and C, B and C, and A and B and C.

[0094] Also, the use of "a" or "an" is employed to describe elements and components described herein. This is done merely for convenience and to give a general sense of the scope of the invention. This description should be read to include one or at least one and the singular also includes the plural unless it states other-

wise.

Claims

1. A system (100), comprising:
an axial field rotary energy device (110) having:

an axis of rotation (201);
a rotor (202) coaxial with the axis (201) and having a shaft (210), bearings (212a, 212b), rotor disks (211) that are coaxial, permanent magnets on each rotor disk (211), and the permanent magnets on each rotor disk (211) face toward each other;
a printed circuit board, PCB stator (220) located axially between the rotor disks (211) to define an air gap (221a, 221b) on each side of the PCB stator (220) between the PCB stator (220) and each of the rotor disks (211);
an enclosure having two enclosure sections (203a, 203b) with at least one of the enclosure sections (203a, 203b) having one or more inspection ports (208) oriented radially, relative to the axis (201), and aligned with the PCB stator (220) and the air gaps (221a, 221b) between the PCB stator (220) and the rotor disks (211), such that the inspection port (208) provides a direct line of sight to the air gaps (221a, 221b);
bearing caps (204a, 204b) and bearings (212a, 212b) mounted to the rotor (202);
at least one annular shim (213) located between a respective bearing cap (204a, 204b) and a respective bearing (212a, 212b), wherein preferably an axial position of the rotor (202) is adjusted and widths of the air gaps (221a, 221b) are changed by adding or removing annular shims (213); and the system (100) further comprises:
a variable frequency drive, VFD, assembly (120) coupled to the axial field rotary energy device (110) and comprising:
a flexible conduit (304) that extends between a VFD housing (301) and the axial field rotary energy device (110), wherein the flexible conduit (304) is configured to adapt to different sizes of axial field rotary energy devices (110).

2. The system (100) of claim 1, wherein at least one of the bearing caps (204a, 204b) comprises a grounding brush (205), preferably the at least one of the bearing caps (204a, 204b) having a slot configured to receive the grounding brush (205).
3. The system of claim 1 or 2, wherein the bearings (212a, 212b) have different sizes.
4. The system of any of the preceding claims further

comprising an impeller (230) coupled to the shaft (210) of the rotor (202).

5. The system of claim 4, wherein the impeller (230) has retention tabs (231) that engage with a groove (206) in the shaft (210) to retain the impeller (230) on the shaft (210).
6. The system of any of the preceding claims further comprising at least one metal shim (222) located between the PCB stator (220) and at least one of the enclosure sections (203a, 203b) of the axial field rotary energy device (110).
7. The system of claim 6, wherein the at least one metal shim (222) axially couples the PCB stator (210) to the enclosure sections (203a, 203b) to transfer heat from the PCB stator (210) to the enclosure sections (203a, 203b).
8. The system (100) of any of the preceding claims, wherein the at least one metal shim (222) comprises metal alloy, copper, aluminum, or copper foam.
9. The system (100) of claim 8, wherein the metal shim (222) is segmented and/or wherein the metal shim (222) is available in different thicknesses.
10. The system (100) of any of the preceding claims, wherein the axial field rotary energy device (110) and the VFD housing achieves a degree of protection IP54 according to IEC60034-5 or higher.
11. The system (100) of any of the preceding claims, wherein the VFD assembly (120) further comprises a rectifier module (122), a DC bus module (123), an inverter module (121), and a control module (124).
12. The system (100) of any of the preceding claims, wherein the enclosure sections (203a, 203b) are clam shell enclosure sections.
13. The system (100) of any of the preceding claims, wherein each enclosure section (203a, 203b) comprises a channel (214) configured to receive a gasket or O-ring that provides a seal between each of enclosure sections (203a, 203b) and the respective bearing caps (204a, 204b).
14. The system (100) of any of the preceding claims comprising four inspection ports (208) that are uniformly spaced around the circumference of one of the enclosure sections (203a).
15. The system (100) of any of the preceding claims, wherein the VFD housing (301) comprises a plurality of fins (305a, 305b) located along two opposite sides of the VFD housing (301).

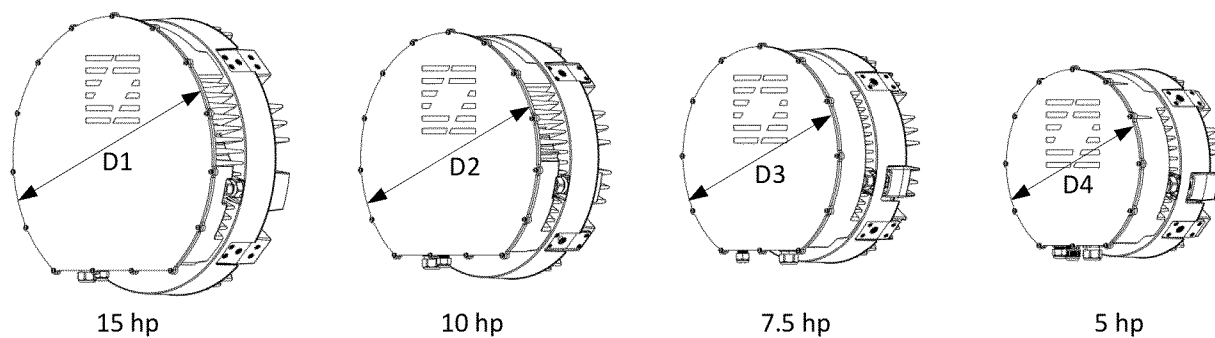


FIG. 1
PRIOR ART

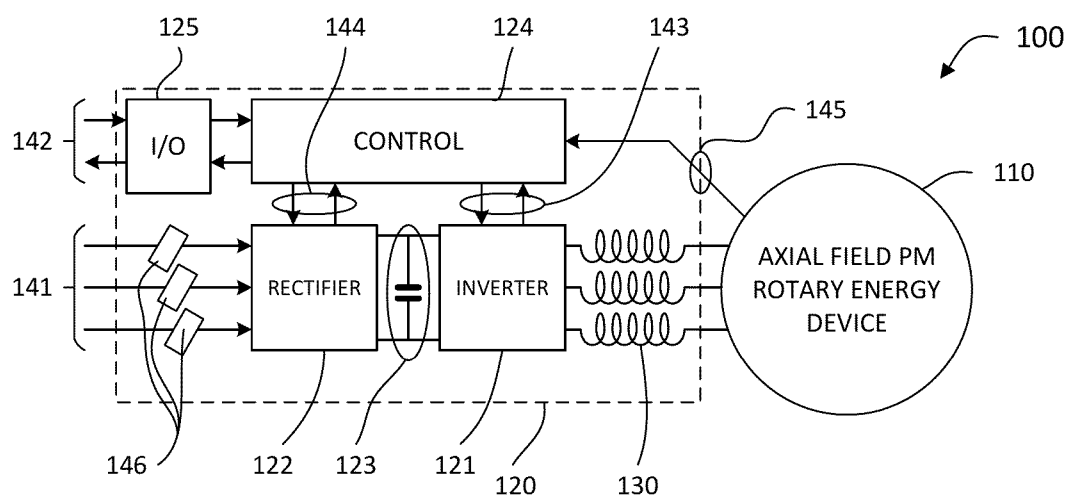


FIG. 2

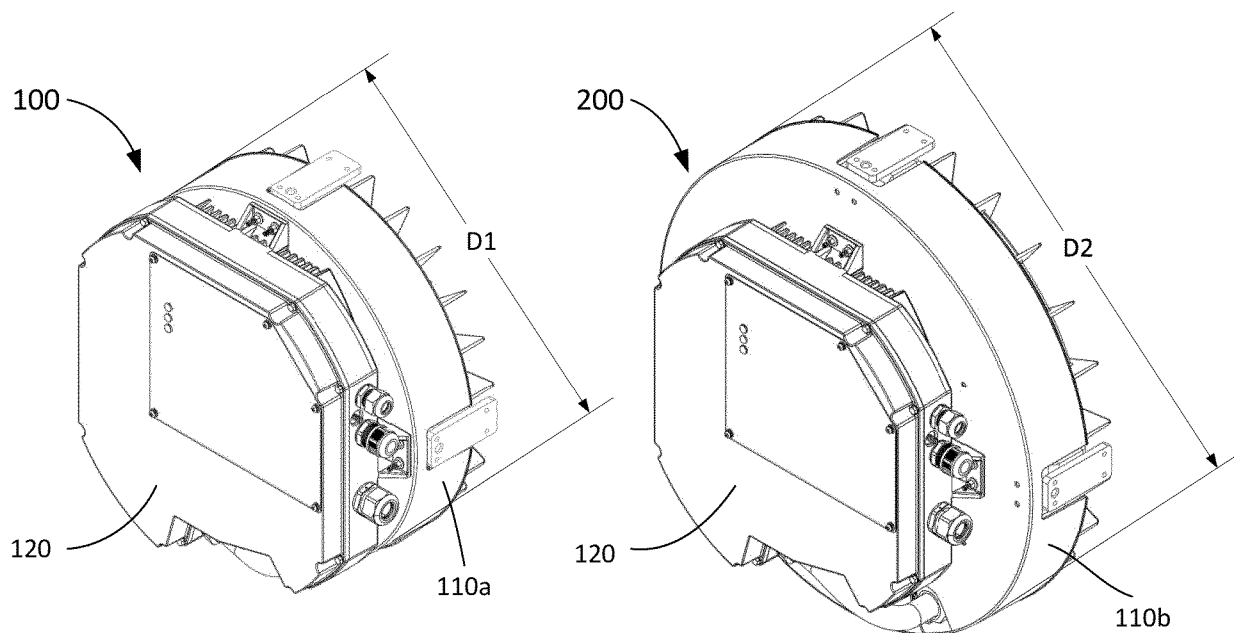


FIG. 3

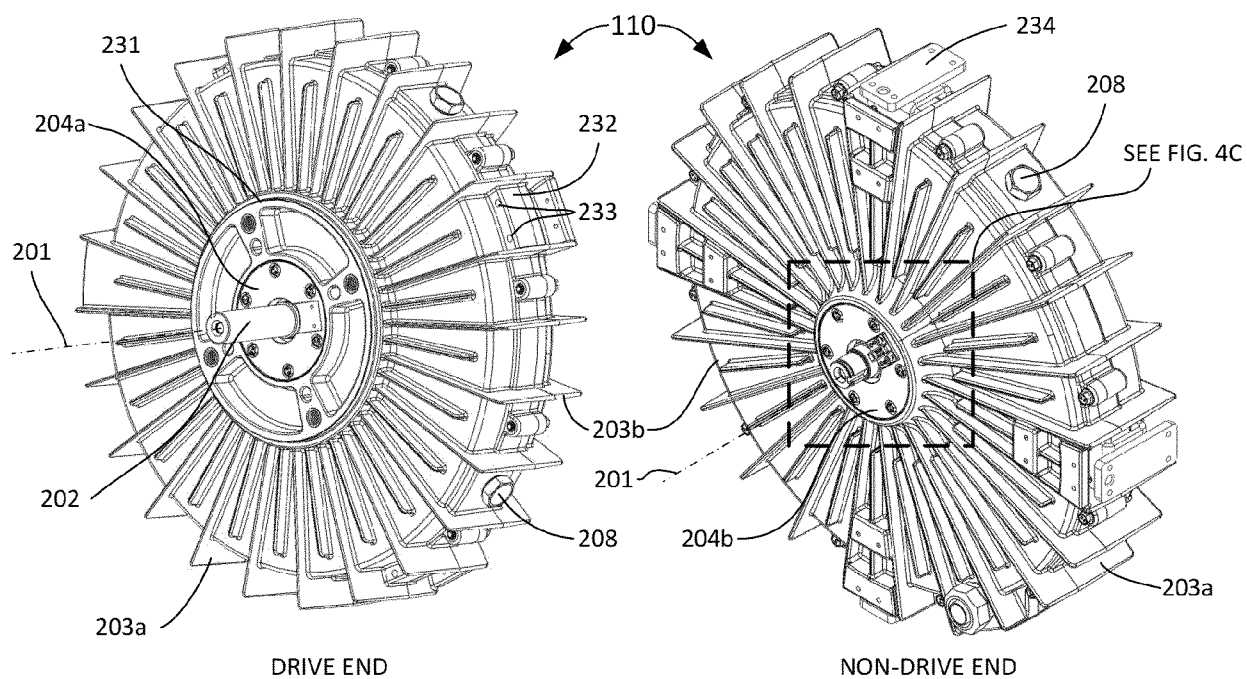


FIG. 4A

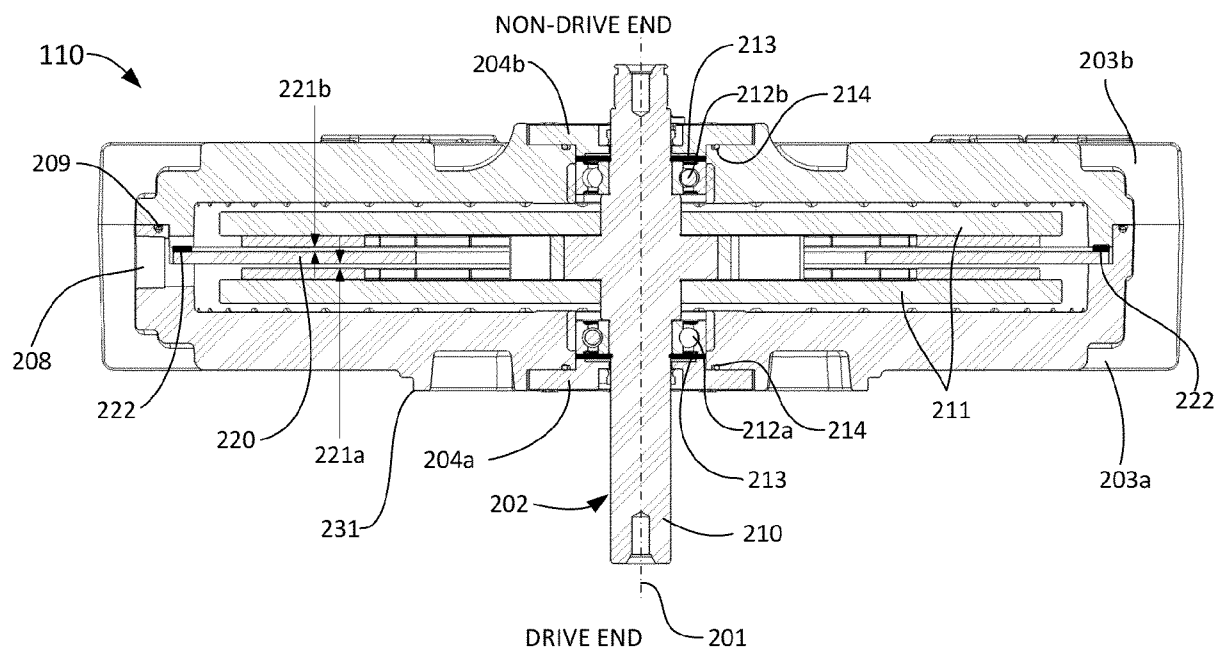


FIG. 4B

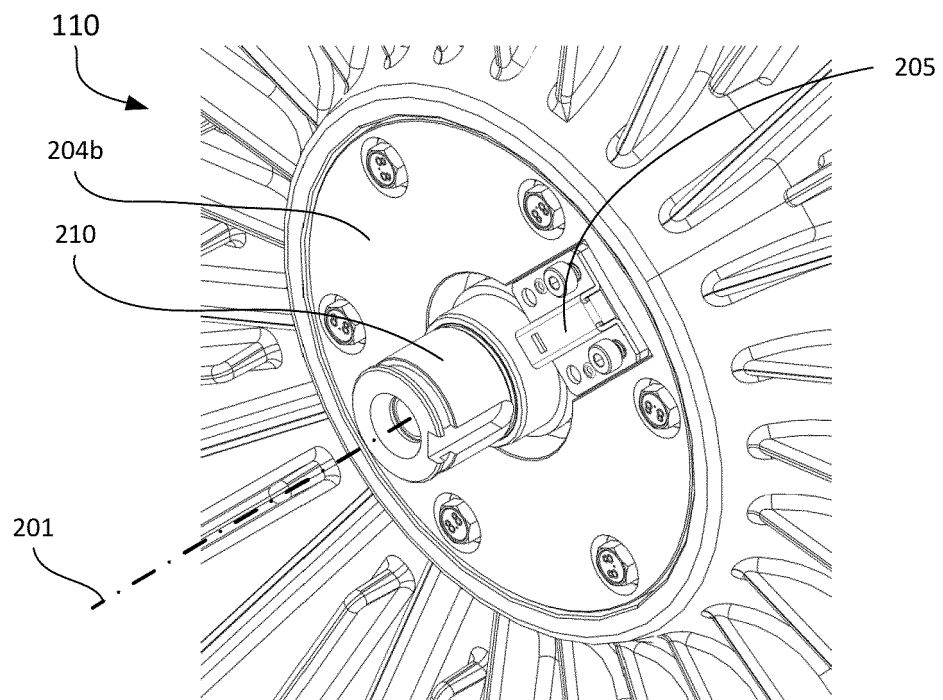


FIG. 4C

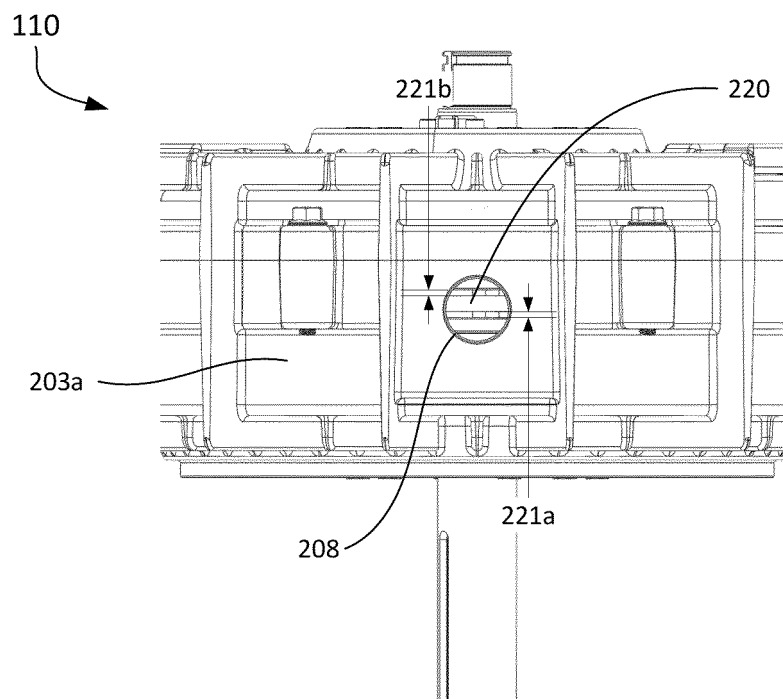


FIG. 4D

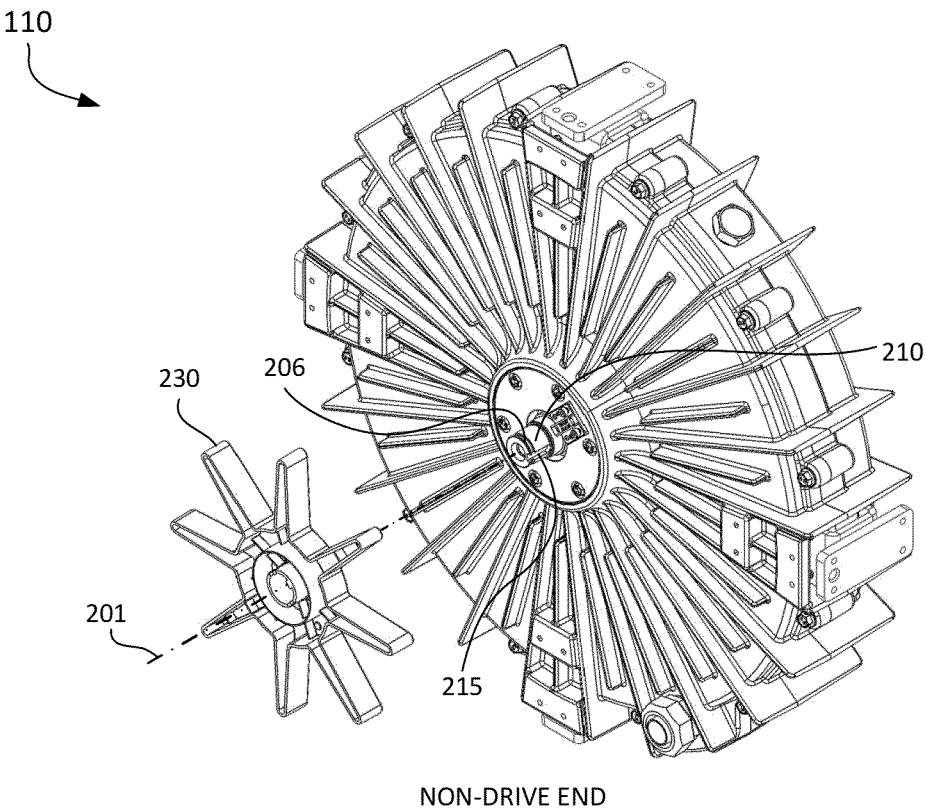


FIG. 5A

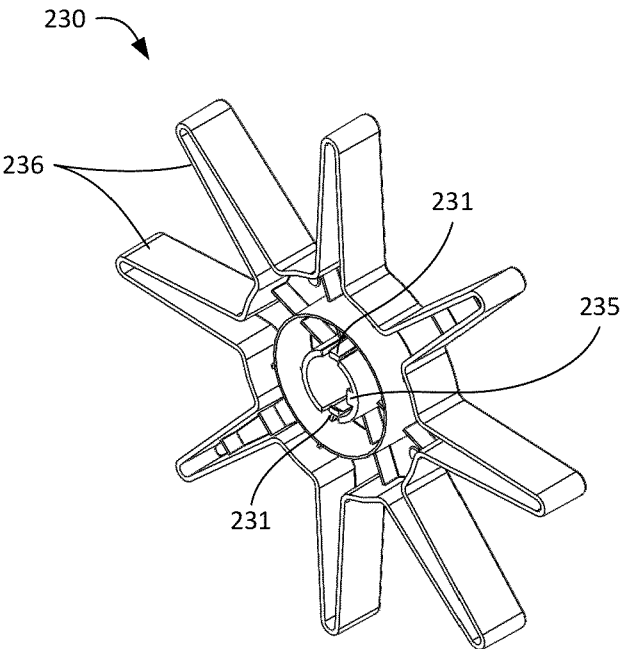


FIG. 5B

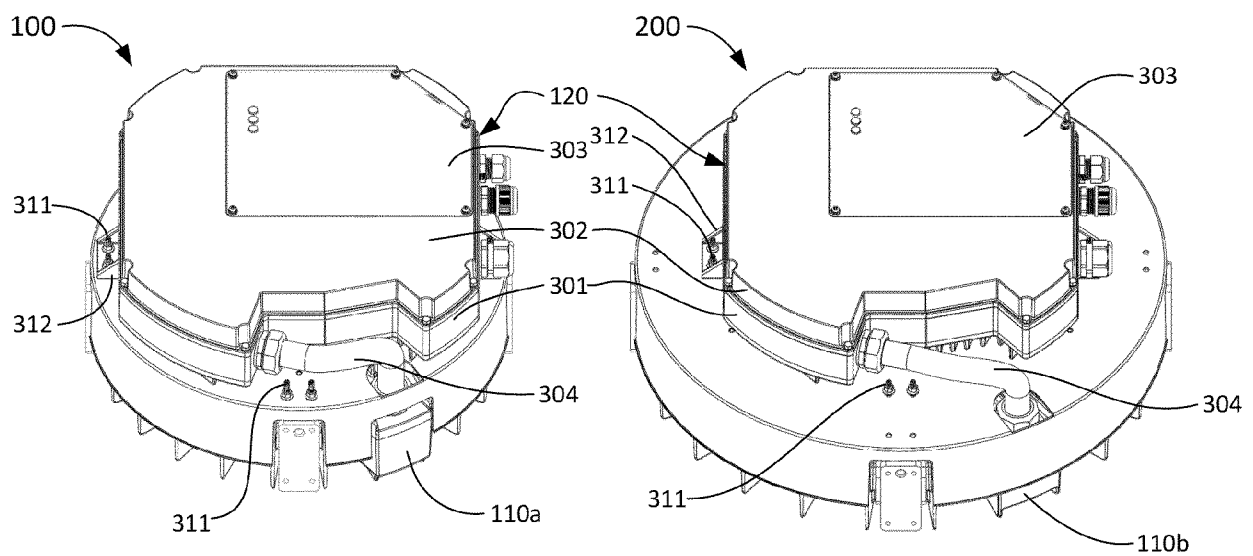


FIG. 6A

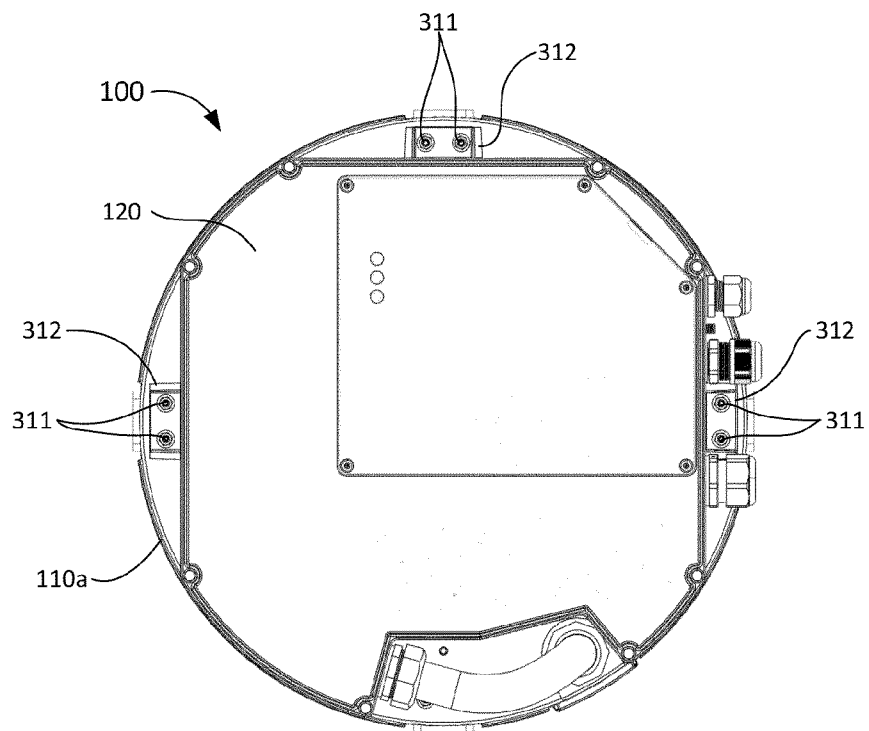


FIG. 6B

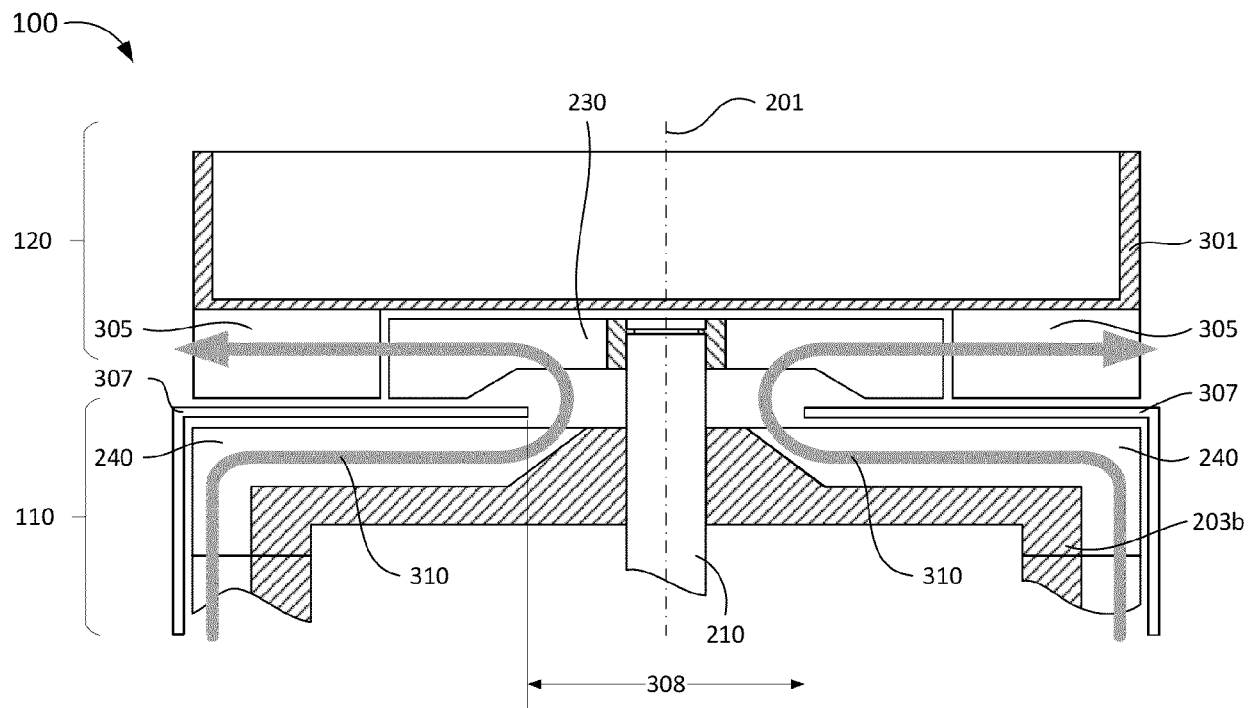


FIG. 7A

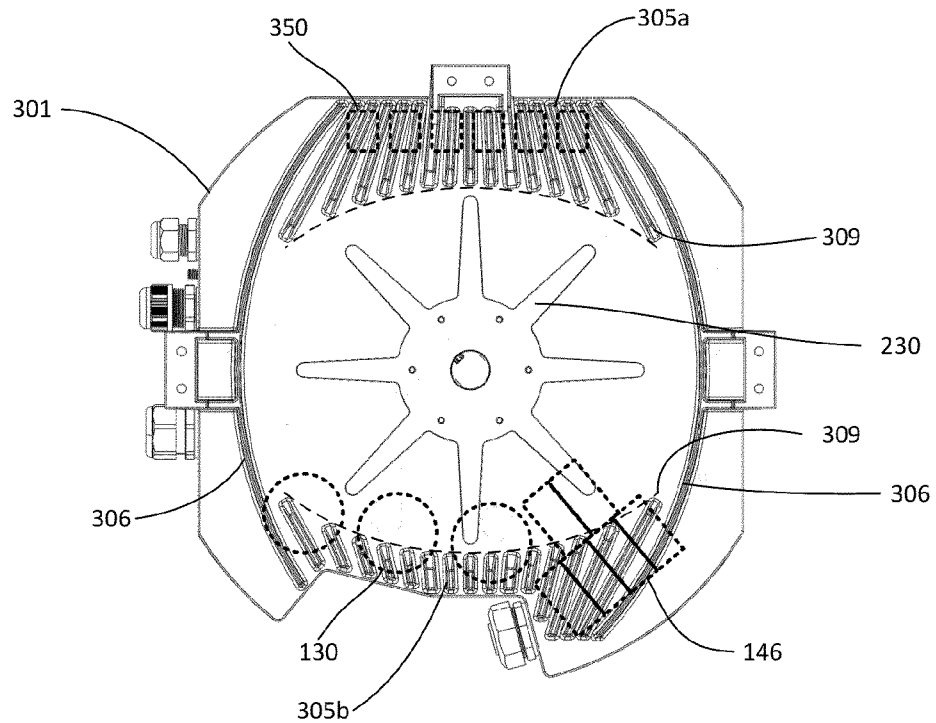


FIG. 7B

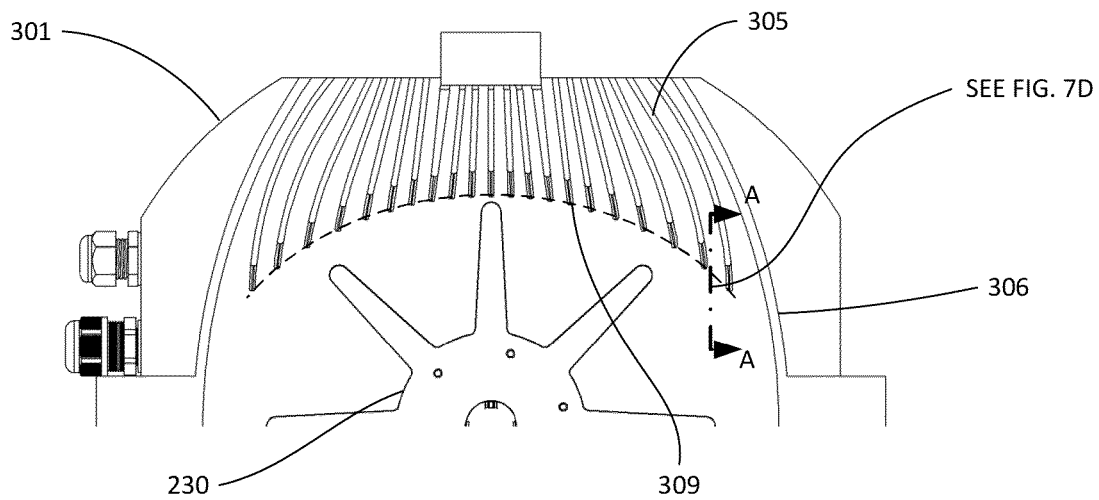
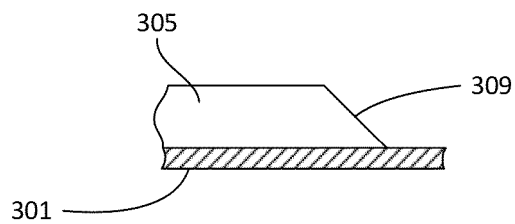


FIG. 7C



SECTION A-A

FIG. 7D

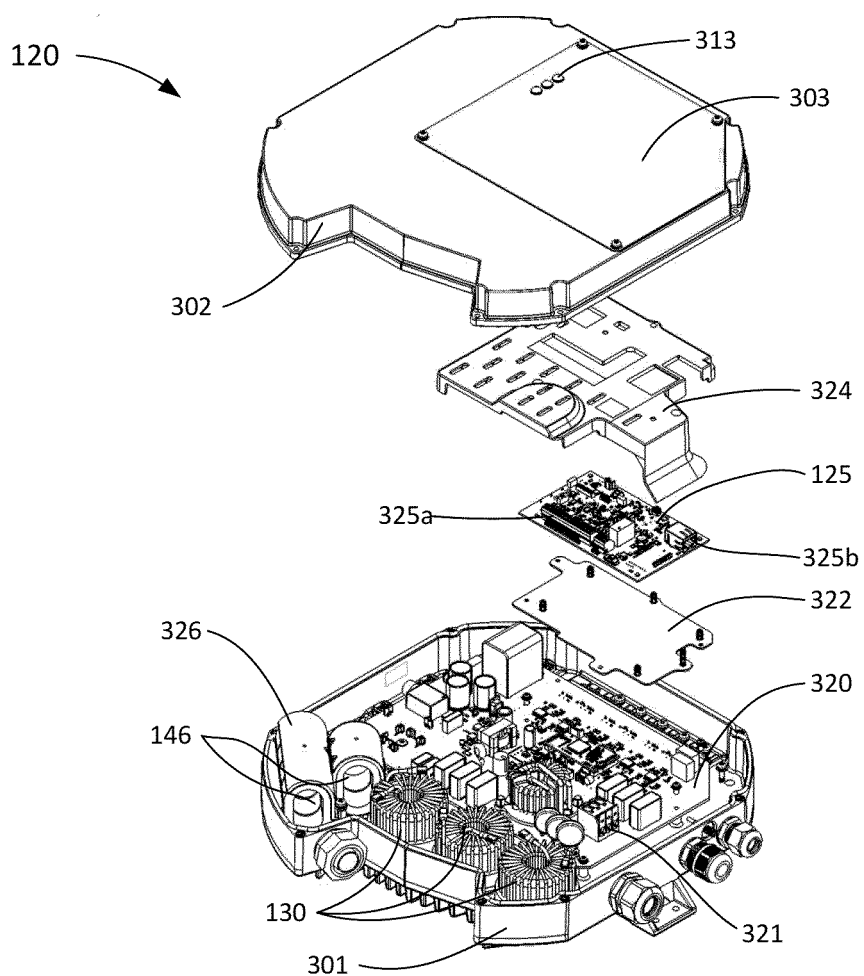


FIG. 8A

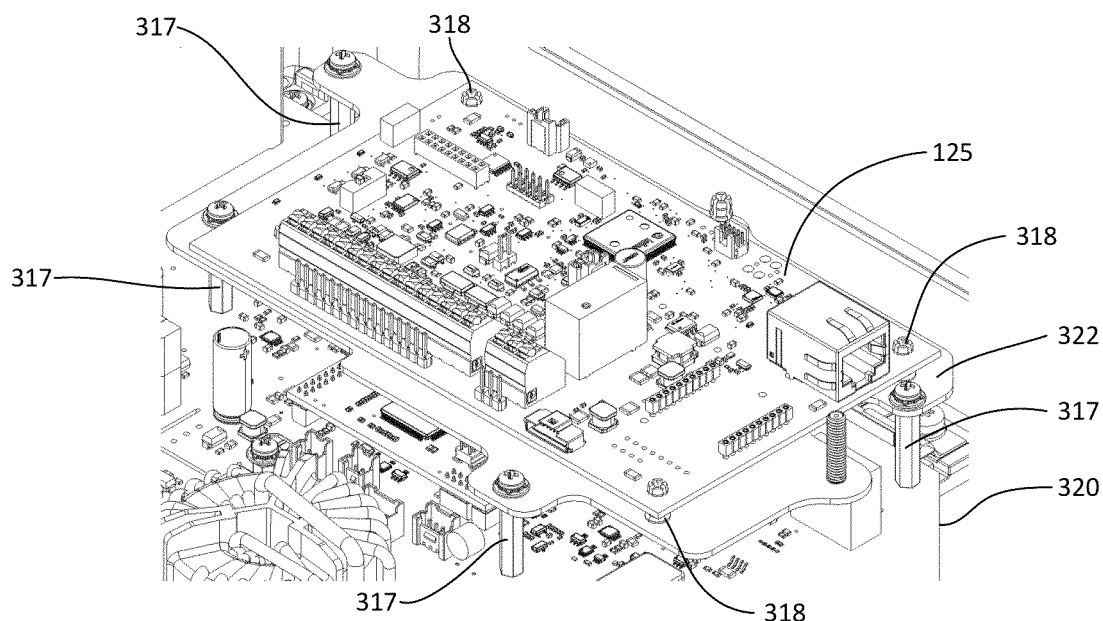


FIG. 8B

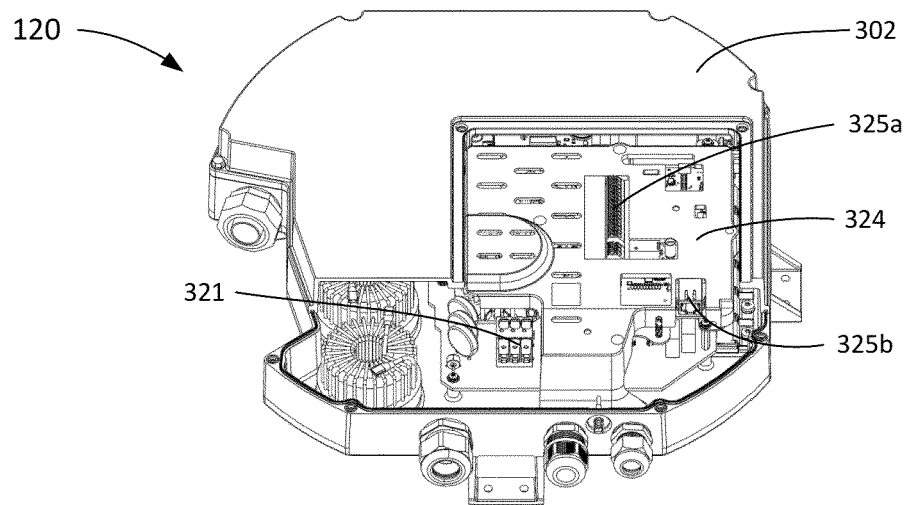


FIG. 8C

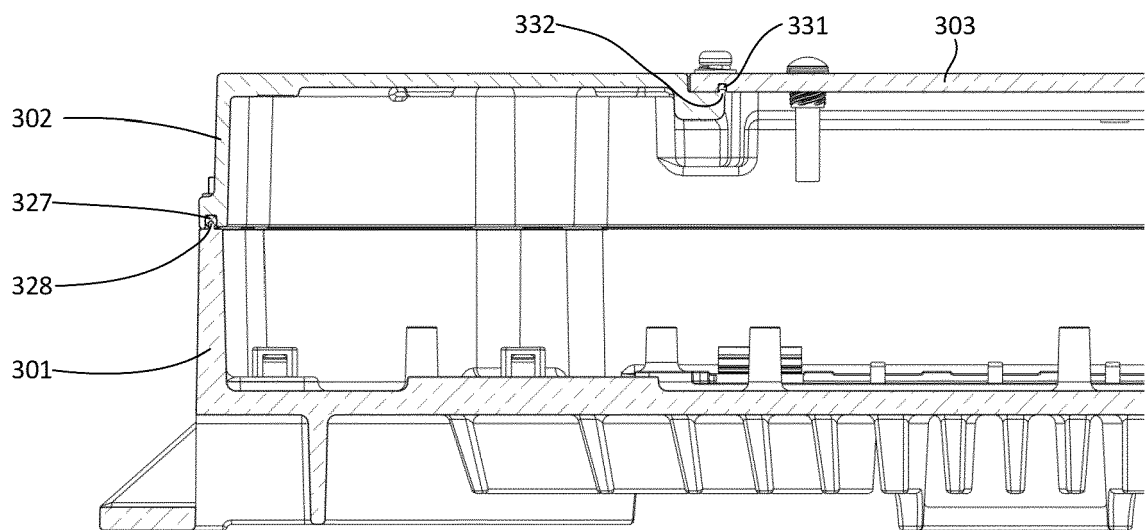


FIG. 9

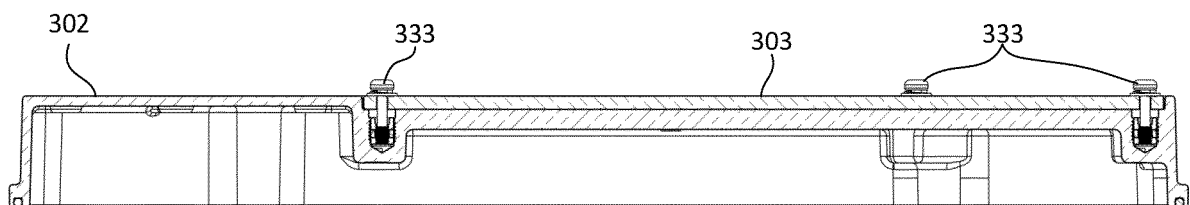


FIG. 10

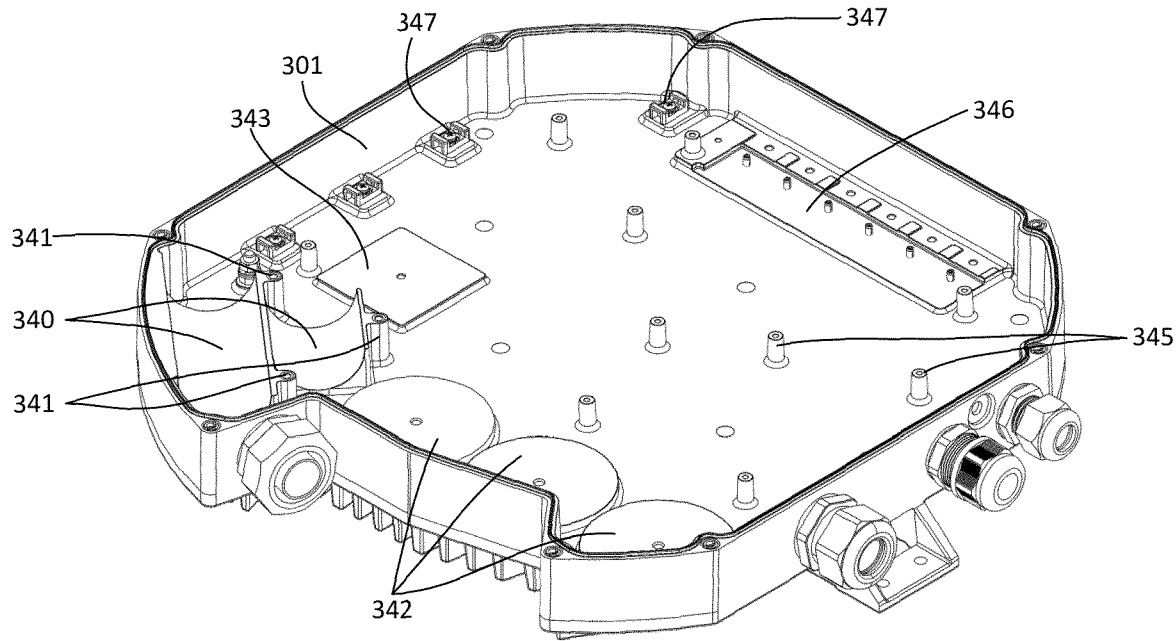


FIG. 11A

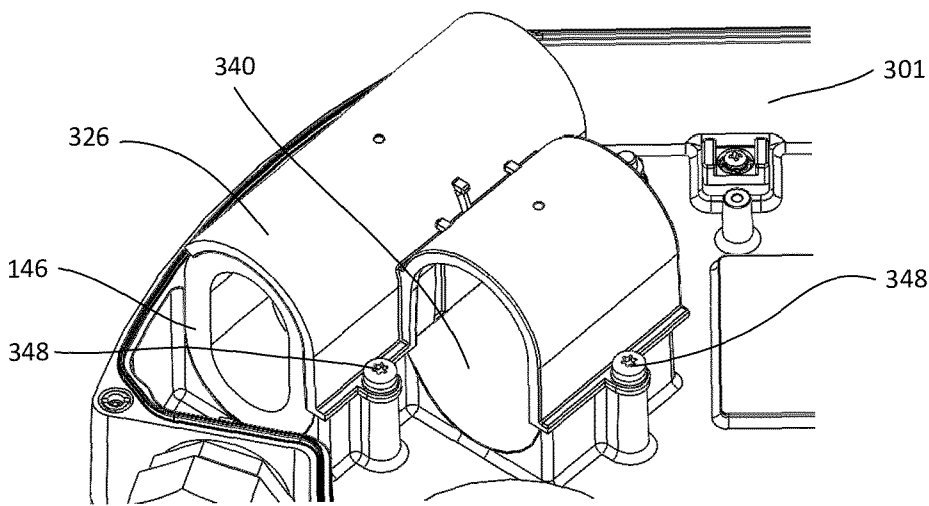


FIG. 11B

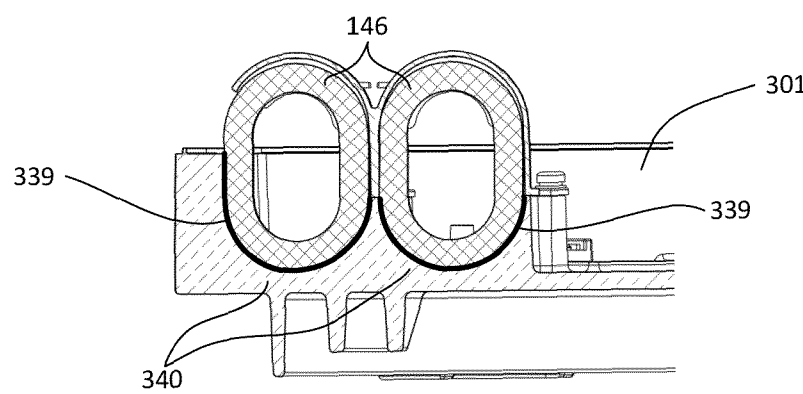


FIG. 11C

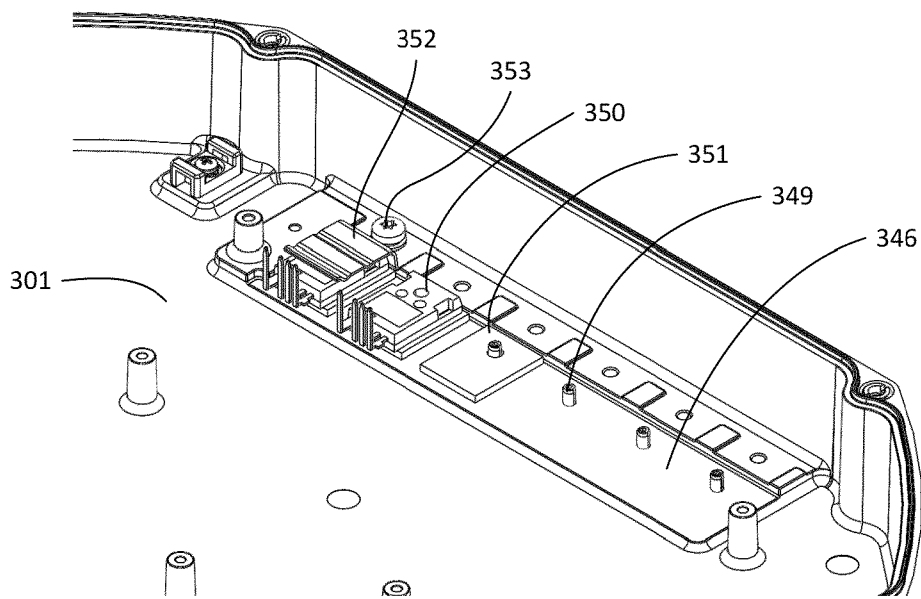


FIG. 11D

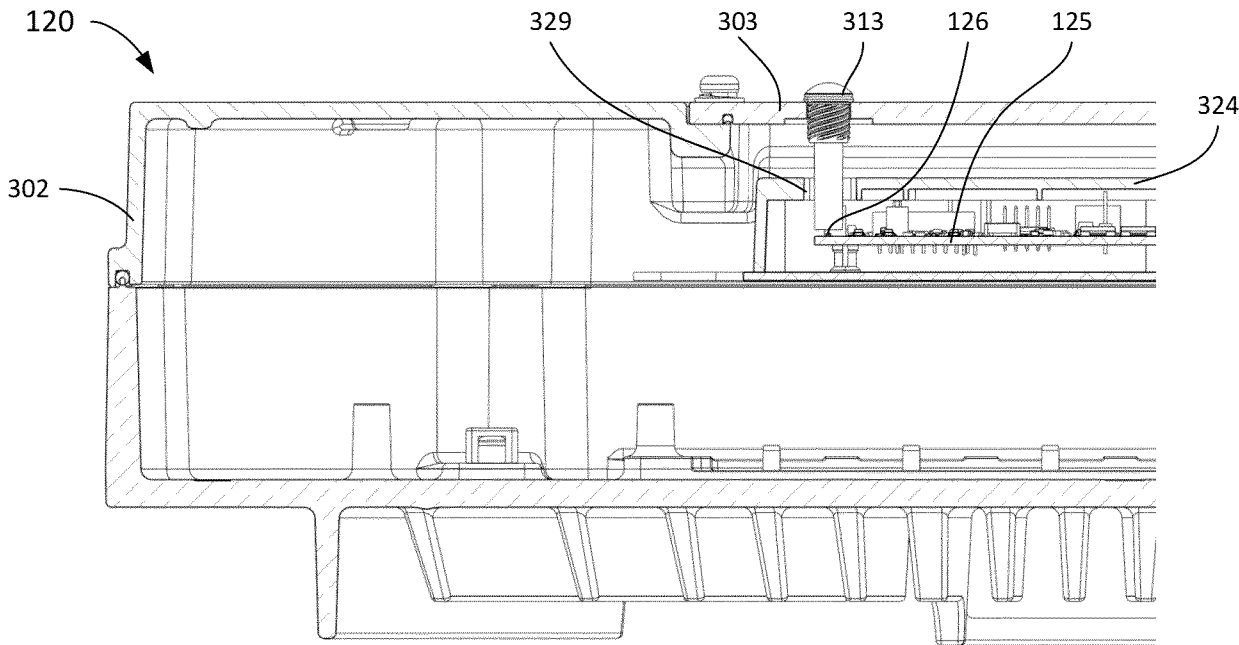


FIG. 12



EUROPEAN SEARCH REPORT

Application Number

EP 24 19 9665

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	DE 10 2022 104152 A1 (SCHAEFFLER TECHNOLOGIES AG [DE]) 24 August 2023 (2023-08-24) * paragraph [0031] - paragraph [0033]; figures 1-4 *	1 - 15	INV. H02K5/22 H02K5/18 H02K21/24 H02K11/40
A	US 2005/127675 A1 (KIRKPATRICK SAMUEL J [GB] ET AL) 16 June 2005 (2005-06-16) * paragraphs [0025], [0033]; figures 1-4 *	1 - 15	
A	US 2023/044158 A1 (LEE RANDAL A [US] ET AL) 9 February 2023 (2023-02-09) * paragraph [0030]; figure 9 * * paragraph [0061] *	1 - 15	
			TECHNICAL FIELDS SEARCHED (IPC)
			H02K
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
The Hague		26 February 2025	Contreras Sampayo, J
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 24 19 9665

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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26-02-2025

10

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE 102022104152 A1	24-08-2023	DE 102022104152 A1	24-08-2023
		WO 2023160742 A1	31-08-2023

US 2005127675 A1	16-06-2005	EP 1544981 A2	22-06-2005
		US 2005127675 A1	16-06-2005
		US 2006125239 A1	15-06-2006

US 2023044158 A1	09-02-2023	AU 2021208478 A1	21-07-2022
		BR 112022013968 A2	11-10-2022
		CA 3163073 A1	22-07-2021
		CN 114982096 A	30-08-2022
		DE 212021000273 U1	26-07-2022
		GB 2606926 A	23-11-2022
		JP 2023509624 A	09-03-2023
		KR 20220120700 A	30-08-2022
		US 2021135526 A1	06-05-2021
		US 2021135549 A1	06-05-2021
		US 2021218304 A1	15-07-2021
		US 2023044158 A1	09-02-2023
		US 2024429765 A1	26-12-2024
		WO 2021146139 A1	22-07-2021
		WO 2021146244 A1	22-07-2021

35

40

45

50

55

EPO FORM P0459

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 10141803 B [0002]
- US 10135310 B [0002]
- US 10340760 B [0002]
- US 10141804 B [0002]
- US 10186922 B [0002]
- US 11183896 A [0002]
- US 11509179 B [0002]